(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 June 2002 (27.06.2002)

PCT

(10) International Publication Number
WO 02/49718 A1

(51) International Patent Classification[7]: A61N 1/37, G01R 31/36

(21) International Application Number: PCT/SE01/02726

(22) International Filing Date: 6 December 2001 (06.12.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0004772-0 19 December 2000 (19.12.2000) SE

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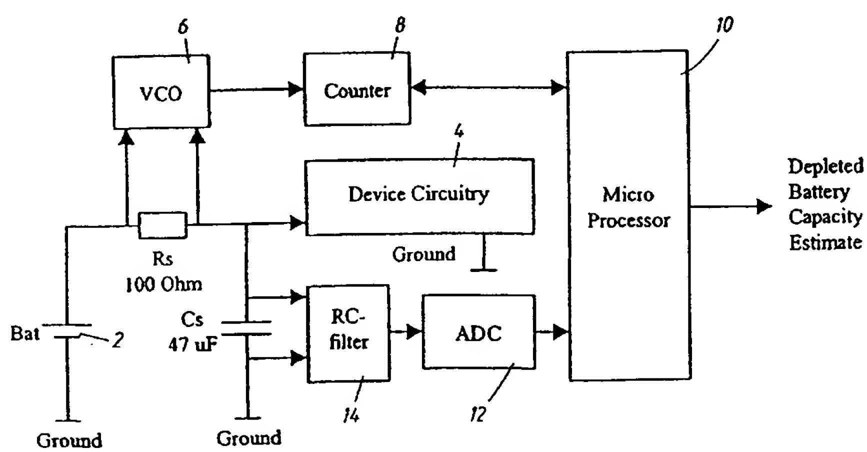
(81) Designated State (*national*): US.

(84) Designated States (*regional*): European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).

**Published:**
— *with international search report*

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

(54) Title: METHOD AND APPARATUS FOR DETERMINING DEPLETED CAPACITY OF A BATTERY




(57) Abstract: In a method for determining depleted capacity of a battery (2) of CFx type used in an implantable medical device average values of battery voltage and current drawn for the battery (2) are measured during a measurement time. The lenght of this measurement time exceeds a battery voltage recovery time after a load change. Predetermined relations between, on one hand, combinations of average values of voltage and current and, on the other hand, depleted battery capacity are used for determining depleted capacity of the battery for the measured average voltage and current. An apparatus for determining depleted capacity of a battery of this type used in an implantable device comprises averaging means provided to determine average values of battery voltage and current drawn from the battery (2) during a measurement time. The lenght of the measurement time exceeds a battery voltage recovery time after a load change. A determining means is provided for determining actual depleted battery capacity from predetermined relations between, on one hand, combinations of average values of voltage and current and, on the other, depleted battery capacity. A pacemaker comprises such an appartus.

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# METHOD AND APPARATUS FOR DETERMINING DEPLETED CAPACITY OF A BATTERY

### *Technical Field*

The present invention relates to a method and an apparatus for determining depleted capacity of a battery of $CF_x$ type used in an implantable medical device.

### *Background*

So called $CF_x$ (Coal monoFluoride) batteries offer the possibility to use fast microprocessors in implantable medical devices like pacemakers, since this type of battery has the capability of delivering current pulses in the milliampere range required by most suitable microprocessors. Further, there is a growing interest in multi-chamber pacing and also in high rate pacing for arrhytmia suppression and termination which also increases the need of the battery to deliver higher battery current. Future products will require high speed and long range telemetry, which also requires higher battery current.

However, the determination of the state of discharge or remaining capacity of this kind of battery gives today rise to considerable difficulties, since there is no single electrical quantity which is well correlated to remaining usable battery capacity.

The battery voltage exhibits very long time constants after load changes and as a consequence there is no useful relation between the instantaneous battery voltage and the state of discharge or remaining battery capacity unless the battery load is constant. Measuring the battery impedance is neither useful for this purpose, since it does not provide useful data during the whole discharge period but only in the latter part of the battery lifetime. Thus, known conventional methods of determining the remaining capacity of batteries used in implantable medical devices cannot be used for $CF_x$ type of batteries.

The purpose of the present invention is therefore to propose a new technique for determining the status of $CF_x$ type batteries, when used in implantable medical devices, especially implantable heart stimulators.

***Disclosure of th Inv nti n***

This purpose is obtained by a method according to claim 1 and an apparatus according to claim 9.

Thus if the battery voltage and the current drawn for the battery are averaged over a sufficiently long period these average values can be used for determining the remaining capacity of the battery. The voltage and current are averaged over a measurement time exceeding the length of a battery voltage recovery time after a load change, the measurement time exceeding the recovery time preferably by a predetermined factor equal to a number between 5 and 10. The recovery time can be defined as the time needed for the battery voltage to reach a certain percentage, e.g. 90 %, of its steady state level.

According to another advantageous embodiment of the method according to the invention said average values of voltage and current are entered into a predetermined look-up table providing depleted battery capacity for different average voltage and current combinations. In practice such a look-up table is available from e.g. the battery manufacturer Wilson and Greatbatch based on constant current data. Experiments have, however, shown that if the battery voltage and current are averaged over a sufficiently long measurement time combinations of the average voltage and average current values can be used for obtaining reliable values of depleted battery capacity from such a table.

According to yet other advantageous embodiments of the method according to the invention depleted battery capacity is also determined by time integrating the total current drawn from the battery. This technique for determining depleted battery capacity is per se previously known when applied to other types of batteries for implantable medical devices, see e.g. US 5 769 873. According to the invention an alarm is preferably triggered if the difference between depleted battery capacities, determined from measured average values of battery voltage and current and determined by time integration of the current drawn from the battery, respectively, exceeds a predetermined threshold value. The triggering of the alarm then indicates that the depleted battery capacity has to be further considered or investigated.

According to an advantageous embodiment of the apparatus according to the invention said averaging means are adapted to determine said average values by sampling and integrating battery voltage and current during said measurement

time. As discussed above the measurement time is in practice comparatively long, e.g. 24 h, and the sampling frequency is chosen high enough to get good accuracy of the average values, e.g. a sampling frequency of 256 Hz. With the use of an optional filter in front of an used analogue to digital converter, the sampling frequency can be reduced, e.g. to the range 0.1 to 1 Hz.

According to still other advantageous embodiments of the apparatus according to the invention an impedance measurement means is provided to measure the internal battery impedance when depleted battery capacity reaches a predetermined threshold value and a second determining means is provided to thereafter determine depleted battery capacity from the measured internal impedance. Internal impedance measurements give reliable values of the depleted battery capacity only in the latter part of the battery lifetime. A first triggering means is therefore preferably provided to trigger said impedance measurement means when depleted battery capacity reaches said predetermined threshold value, determined from measured average values of battery voltage and current as described above.

According to yet another advantageous embodiment of the apparatus according to the invention a second triggering means is triggering an alarm if the difference between depleted battery capacities, determined from measured average values of battery voltage and current, and determined by time integration of the current drawn from the battery or determined from the measured internal impedance, respectively, exceeds a predetermined threshold value. Thus, if there are discrepancies in the depleted battery capacities determined by the different methods, this is indicated to the patient and/or the physician such that further investigations can be made. In this way improved security with reference to the battery status is obtained.

## *Brief Description of the Drawings*

To more clearly explain the invention an embodiment of the apparatus according to the invention will now be described in greater detail with reference to the drawings, on which figure 1 is a plot of battery voltage and discharged capacity versus time obtained from measurements on a $CF_x$ type batt ry, figur 2 shows an embodim nt of the apparatus according to the invention, and figur 3 is an exam-

ple of a look-up table suitable for use when determining depleted battery capacity of $CF_x$ type batteries according to the invention.

***Description of Preferred Embodiment***

Figure 1 is a plot of battery voltage and discharged capacity versus time obtained from measurements on a $CF_x$ type battery. The battery was subjected to different load patterns in a 17 weeks test sequence. More precisely figure 1 shows the results obtained for four different load patterns simulating various types of pacemaker loads.

Pattern 1 includes 3 hours of 10 μA load followed by 9 hours of 5 μA load, repeated 14 times, which gives a total time of 7 days. This pattern simulates a typical low current sequence with 3 hours of load threshold (Autocapture) single chamber pacing, followed by 9 hours of inhibition.

Pattern 2 includes a fixed load of 6.25 μA during 7 days, representing the average load of pattern 1.

Pattern 3 includes 3 hours of 100 μA load followed by 9 hours of 5 μA load, repeated 14 times, which gives a total time of 7 days. This simulates 3 hours of high threshold, multiple chambers pacing, followed by 9 hours of inhibition.

Pattern 4 includes a fixed load of 28.75 μA during 7 days, representing the average load of the pattern 3.

Between each week of loads simulating typical pacemaker loads according to patterns 1-4 above one week follows with a heavy load of approximately 900 μA in order to discharge the battery within a reasonably short time. In figure 1 such cycles are shown repeated 8 times. In the figure total depleted battery capacity is also showed as a function of time.

In figure 1 can a. o. be observed that the dynamic impedance is high in the beginning of the battery lifetime and is then successively decreasing. It can also be noted that the recovery time is increasing with the depletion of the battery. Thus at the time of about 60 days in figure 1 steady state is reached after a period of heavy load within a few days, whereas at time 100 days steady state is hardly reached within one week.

In figure 2 an embodiment is shown of the apparatus according to the invention implemented in a pacemaker.

A shunt resistor Rs of typical 100 Ohm is connected to the battery 2 of $CF_x$ type to be tested. This resistor Rs converts the current from the battery 2 to a voltage. The current drain from the battery 2 consists of the internal housekeeping current and the current used for therapeutic treatment, i.e. pacing pulses.

A voltage controlled oscillator (VCO) 6 converts the voltage across the resistor Rs to a pulse train with a frequency, which is proportional to the voltage.

The counter 8 counts the pulse train pulses from the VCO 6. The count is read by the microprocessor 10 every 24 hours. Thereafter the counter 8 is reset by the microprocessor 10 and starts counting for another 24 hours period.

A stabilising capacitor Cs of typical 47 μF is used for stabilising the supply voltage during varying battery current loads.

An analogue to digital converter (ADC) 12, preceded by a RC-filter 14, converts the battery voltage to a digital word. The microprocessor 10 controls the counter 8, reads the ADC 12 and calculates remaining capacity of the battery 2 as will be further explained in the following.

The device circuitry 4 represents the complete normal circuitry of the pacemaker.

The average battery voltage is determined over a period of 24 hours. The battery voltage is sampled by the ADC 12. The 24 hours average voltage is calculated by the microprocessor 10 by calculating the sum of all sampled digital values during 24 hours and then dividing this sum with the number of samples. The voltage is sampled with such a high frequency that good accuracy of the true average value is achieved, e. g. a sampling frequency of 1 Hz.

The average battery current is also calculated over a period of 24 hours. The current from the battery 2 is measured by measuring the voltage across the resistor Rs. The measured voltage is supplied to the VCO 6, which is generating a pulse train with a frequency proportional to the measured voltage, and consequently proportional to the current. This digital signal with a varying frequency is supplied to the counter 8. The counter value is read every 24 hours. The counter 8 is then immediately reset to be ready for counting during the following 24 hours period.

In the embodiment shown in figure 2 a VCO 6 is used for current measurem nts and an ADC 12 is used for voltage measurements. As alternatives either

VCOs or ADCs can be used for both current and voltage measurements. As another alternative the microprocessor can be replaced by hard-wired logic.

The 24 hours average voltage and current values are entered into a look-up table as shown in figure 3 to obtain remaining battery capacity.

The table in figure 3 is an example based on constant load current data available from the battery manufacturer Wilson and Greatbatch. However, experiments have shown that corresponding tables are valid for variable loads when using voltage and current average values determined as described above.

The table in figure 3 is used as follows. The average current for the last 24 hours is determined to e. g. 30 μA. The corresponding average voltage has been determined to e. g. 2.940 V. The 30μA row is then followed in the table until the measured average voltage of 2.940 V is reached. This column in the table is followed to the top of the table where the depleted capacity can be read to 0.6 Ah. Interpolation is used to determine a value for the depleted capacity when one or both of the average voltage and the average load current values are in between the values in the table.

The look-up table is preferably stored in the memory of the microprocessor and the procedure described automated. The invention can then be used as a new advantageous RRT (Recommended Replacement Time) indicator for $CF_x$ type batteries.

CLAIMS

1. A method for determining depleted capacity of a battery of $CF_x$ type used in an implantable medical device, **characterized in** that average values of battery voltage and current drawn from the battery (2) are measured during a measurement time, the length of which exceeds a battery voltage recovery time after a load change, and in that predetermined relations between, on one hand, combinations of average values of voltage and current and, on the other, depleted battery capacity are used for determining depleted capacity of the battery from said measured average voltage and current.

2. The method according to claim 1, **characterized in** that said measurement time exceeds the battery recovery time by a predetermined factor.

3. The method according to claim 2, **characterized in** that said factor equals a number between 5 and 10.

4. The method according to any one of the preceding claims, **characterized in** that said battery recovery time equals a time within the range 3 – 50 h.

5. The method according to any one of the preceding claims, **characterized in** that said measurement time exceeds 24 h.

6. The method according to any one of the preceding claims, **characterized in** that said average values of voltage and current are entered into a predetermined look-up table providing depleted battery capacity for different average voltage and current combinations.

7. The method according to any one of the preceding claims, **characterized in** that depleted battery capacity is also determined by time integrating the total current drawn from the battery.

8. The method according to claim 7, **charact rized in** that an alarm is triggered if the difference between depleted battery capacities, determined from measured average values of battery voltage and current and determined by time integration of the current drawn from the battery, respectively, exceeds a predetermined threshold value.

9. An apparatus for determining depleted capacity of a battery of $CF_x$ type used in an implantable medical device, **characterized in** that averaging means (10,12) are provided to determine average values of battery voltage and current drawn from the battery during a measurement time, the length of which exceeds a battery voltage recovery time after a load change, and in that a determining means is provided for determining actual depleted battery capacity from predetermined relations between, on one hand, combinations of average values of voltage and current and, on the other, depleted battery capacity.

10. The apparatus according to claim 9, **characterized in** that said predetermined relations include a stored, predetermined look-up table of depleted battery capacity for different combinations of average voltage and current and in that said determining means is adapted to enter combinations of measured average voltage and current values into said look-up table to determine actual depleted battery capacity.

11. The apparatus according to claim 9 or 10, **characterized in** that said averaging means (10.12) are adapted to determine said average values by sampling and integrating battery voltage and current during said measurement time.

12. The apparatus according to claim 9 or 10, **characterized in** that said determining means comprises an integrating means for integrating the total current drawn from the battery to determine total charge depleted from the battery.

13. The apparatus according to any one of the claims 9 through 12, **characterized in** that an impedance measurement means is provided to measure the internal battery impedance when depleted battery capacity reaches a predetermined

threshold value, determined from measured average values of battery voltage and current, and in that a second determining means is provided to thereafter determine depleted battery capacity from the measured internal impedance.

14. The apparatus according to claim 13, **characterized in** that a first triggering means is provided to trigger said impedance measurement means when depleted battery capacity reaches said predetermined threshold value, determined from measured average values of battery voltage and current, of depleted battery capacity.

15. The apparatus according to any one of the claims 9-11 and one or more of the claims 12-14, **characterized in** that a second triggering means is triggering an alarm if the difference between depleted battery capacities, determined from measured average values of battery voltage and current, and determined by time integration of the current drawn from the battery or determined from the measured internal impedance, respectively, exceeds a predetermined threshold value.

16. A pacemaker, **characterized** by an apparatus according to any one of the claims 9-15.

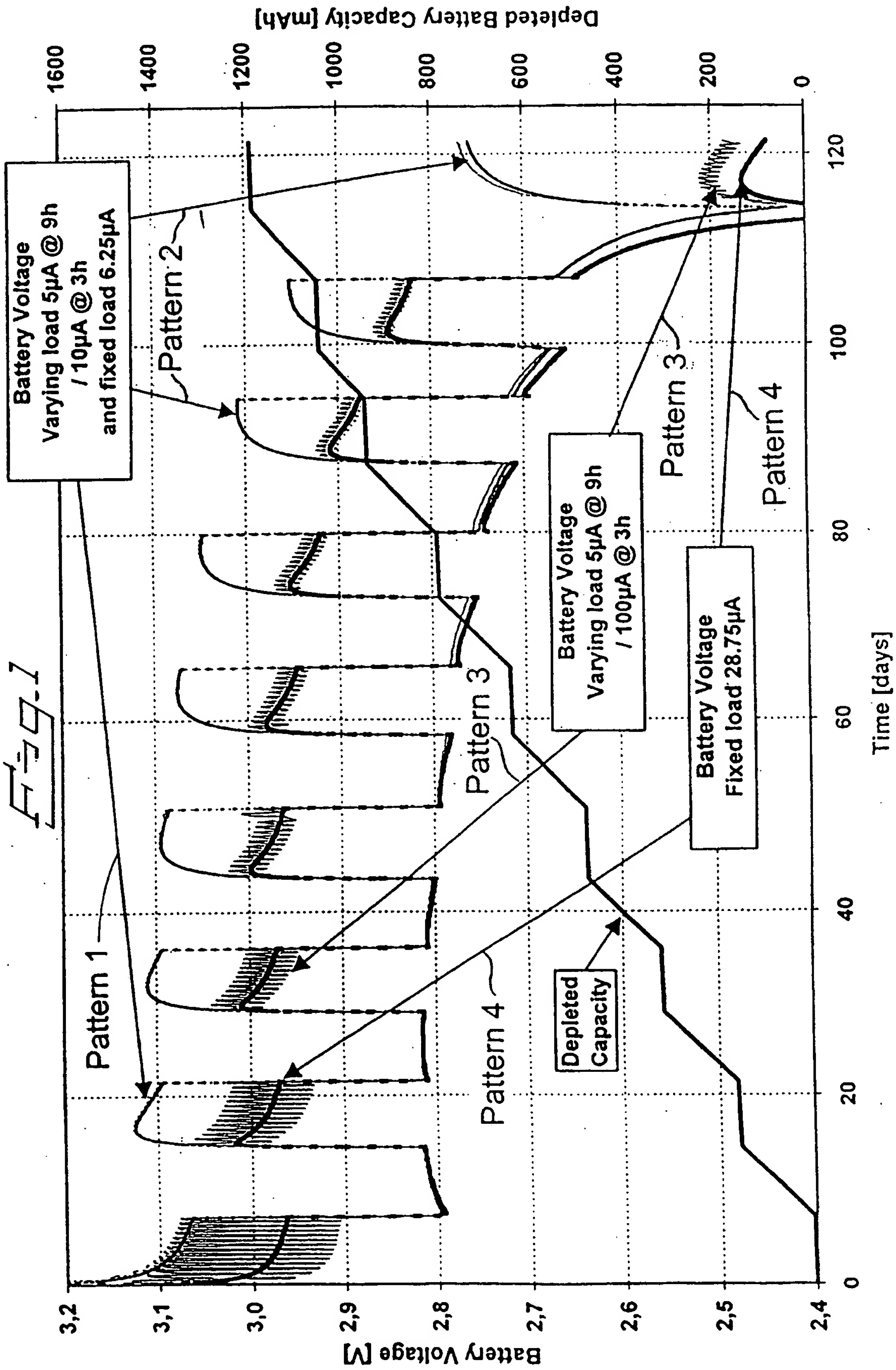
Depleted Battery Capacity [mAh]
1600
1400
1200
1000
800
600
400
200
0
Battery Voltage
Varying load 5µA @ 9h
/ 10µA @ 3h
and fixed load 6.25µA
Pattern 2
Pattern 1
Pattern 3
Pattern 4
Depleted Capacity
Battery Voltage
Varying load 5µA @ 9h
/ 100µA @ 3h
Battery Voltage
Fixed load 28.75µA
Pattern 3
Pattern 4
Time [days]
0
20
40
60
80
100
120
Battery Voltage [V]
3,2
3,1
3,0
2,9
2,8
2,7
2,6
2,5
2,4
Fig.1

Fig. 2

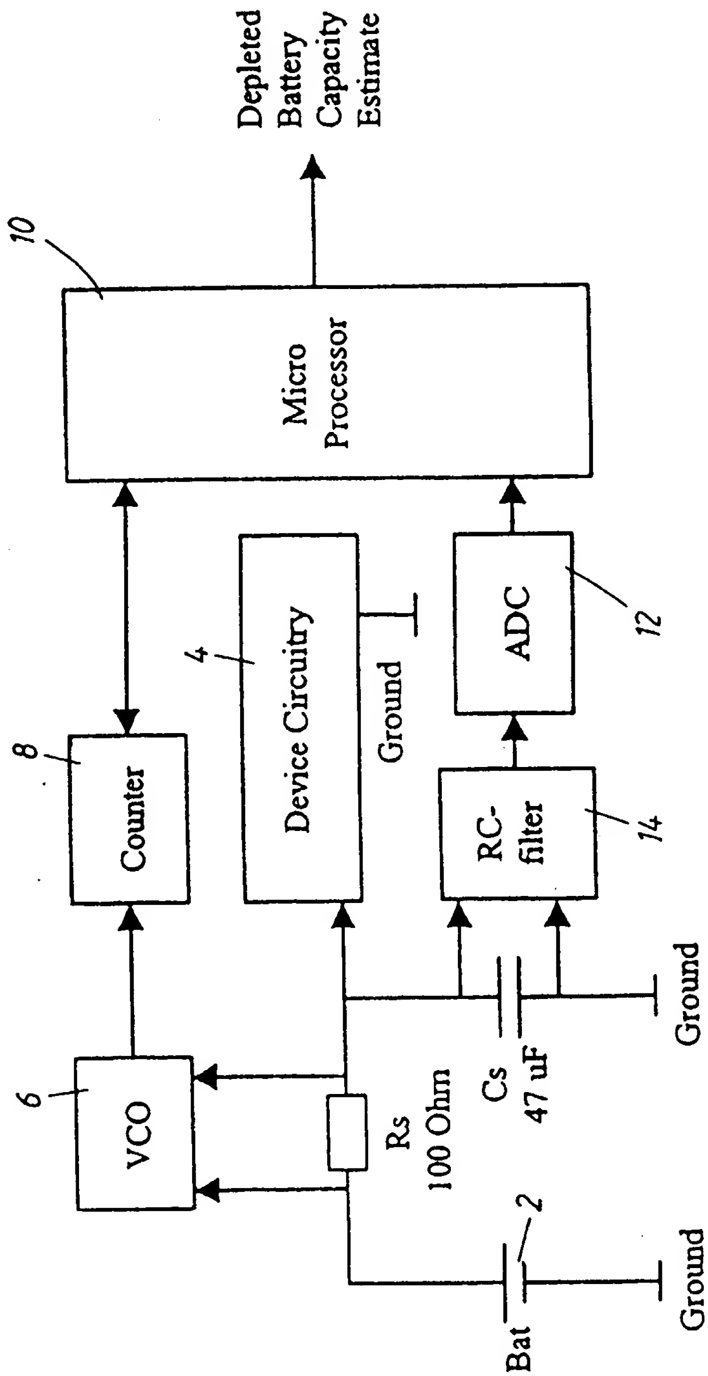
Depleted Battery Capacity Estimate
10
Micro Processor
4
Device Circuitry
Ground
ADC
12
8
Counter
RC-filter
14
6
VCO
Rs
100 Ohm
Cs
47 uF
Ground
2
Bat
Ground

Fig.3

| Depleted capacity | 0.0 Ah | 0.05 Ah | 0.2 Ah | 0.4 Ah | 0.6 Ah | 0.8 Ah | 1.0 Ah | 1.1 Ah | 1.2 Ah |
|---|---|---|---|---|---|---|---|---|---|
| Average Load Current | Average load Voltage | | | | | | | | |
| 20 μA | 3.13 V | 2.98 V | 2.99 V | 2.98 V | 2.95 V | | | | |
| 30 μA | 3.080 V | 2.965 V | 2.975 V | 2.960 V | 2.940 V | 2.90 V | | | |
| 46 μA | 3.045 V | 2.95 V | 2.955 V | 2.945 V | 2.92 V | 2.88 V | 2.80 V | 2.72 V | 2.15 V |
| 90 μA | 2.95 V | 2.915 V | 2.92 V | 2.91V | 2.89 V | 2.85 V | 2.775 V | 2.675 V | 2.20 V |

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 01/02726

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: A61N 1/37, G01R 31/36
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: A61N, G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI-DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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| A | | 2-5,7-8, 12-15 |
| | -- | |
| Y | EP 0763747 A1 (MEDTRONIC, INC.), 19 March 1997 (19.03.97), column 8 - column 10; column 16, line 2 - line 26, figure 3, abstract | 1,6,9-11,16 |
| A | | 2-5,7,8, 12-15 |
| | -- | |

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
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| 18 March 2002 | 21 -03- 2002 |
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

International application No.
PCT/SE 01/02726

| Patent document cited in search report | | | Publication date | Patent family member(s) | | | Publication date |
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| EP | 0763747 | A1 | 19/03/97 | SE | 0763747 | T3 | |
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| | | | | DE | 69423918 | D,T | 03/08/00 |
| | | | | EP | 0706407 | A,B | 17/04/96 |
| | | | | SE | 0706407 | T3 | |
| | | | | JP | 2871097 | B | 17/03/99 |
| | | | | JP | 8508437 | T | 10/09/96 |
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| US | 5391193 | A | 21/02/95 | NONE | | | |
| WO | 0105466 | A1 | 25/01/01 | SE | 9902734 | D | 00/00/00 |